



Lisbon School  
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Universidade de Lisboa



# NETWORK SCIENCE

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# Learning Goals

- Understand the context of network Science
- Explain main concepts and measurements
- Use mail tools
- Apply to specific context

# Agenda

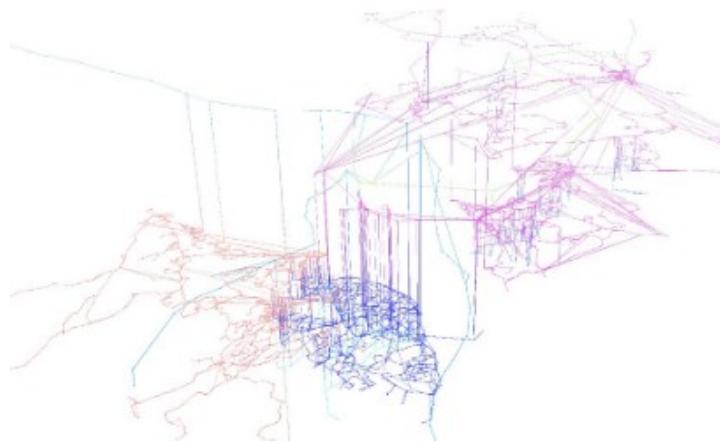
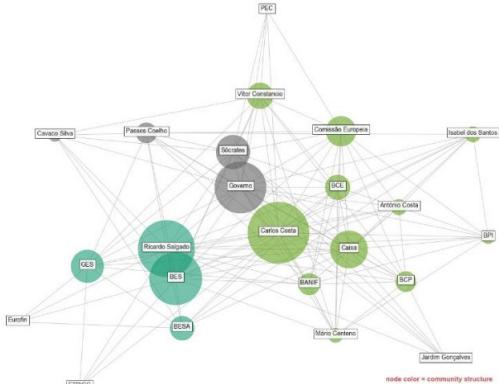
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- Complex Network
- Network Elements
- Measurements
- Node Degree
- Networks metrics
- Node metrics
- Tools
- Applications
- Challenges



# Complex Network

- telecommunication networks
- computer networks
- biological networks
- cognitive and semantic networks
- social networks



# Network Elements

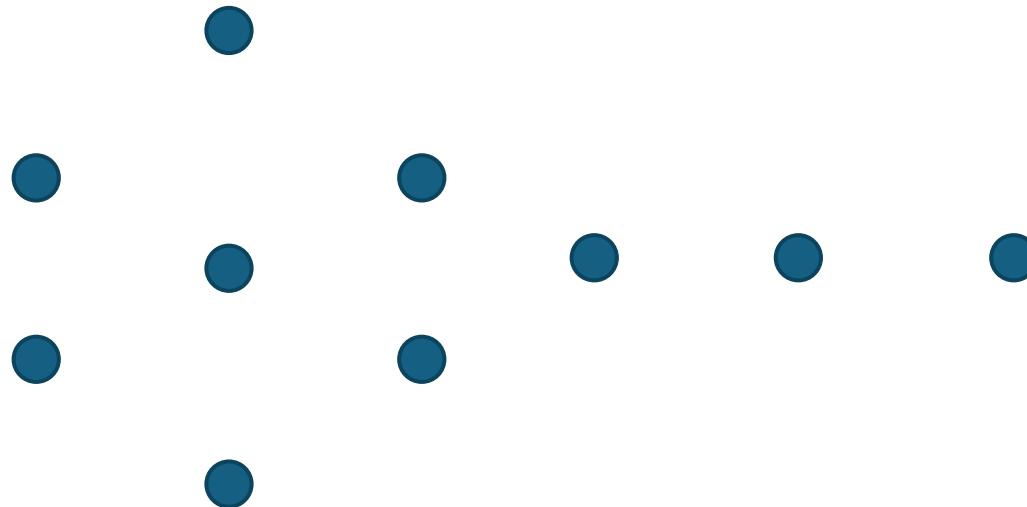
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- "vertex" and "edge" (Mathematics)
- "nodes" and "connections" (or links) (Computer Science)
- "actors" (or "agents") and "relationships" (Sociology)
- "site" and "bond" (Physics)
- "dot" and "arcs" (or ties)



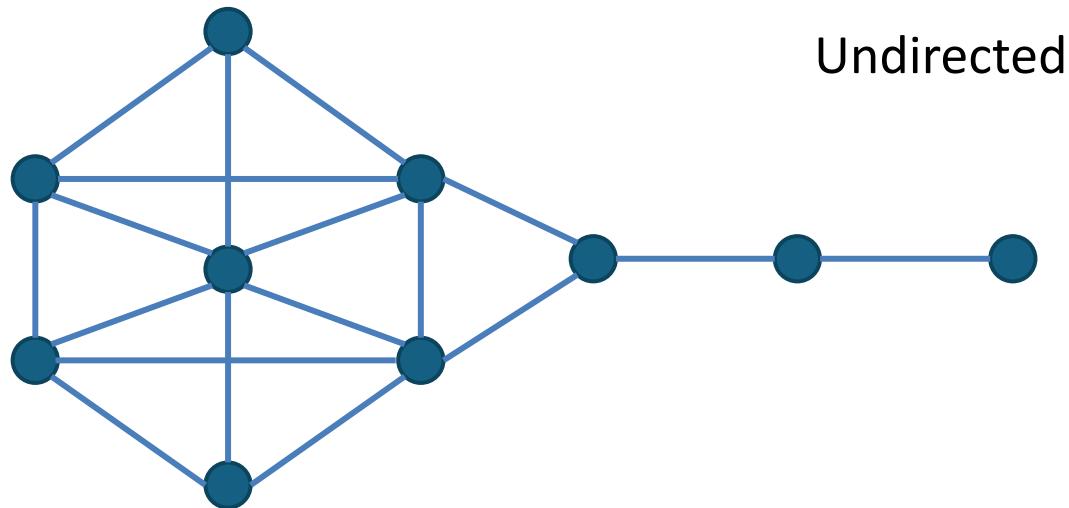
# Network Elements

- Vertex, nodes and actors



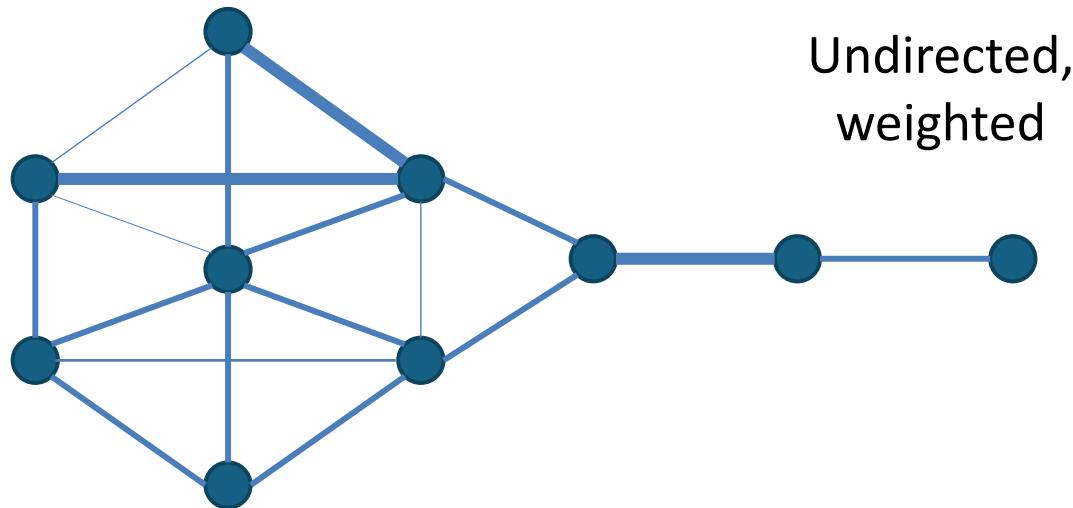
# Network Elements

- Edges, arcs, links and relationships



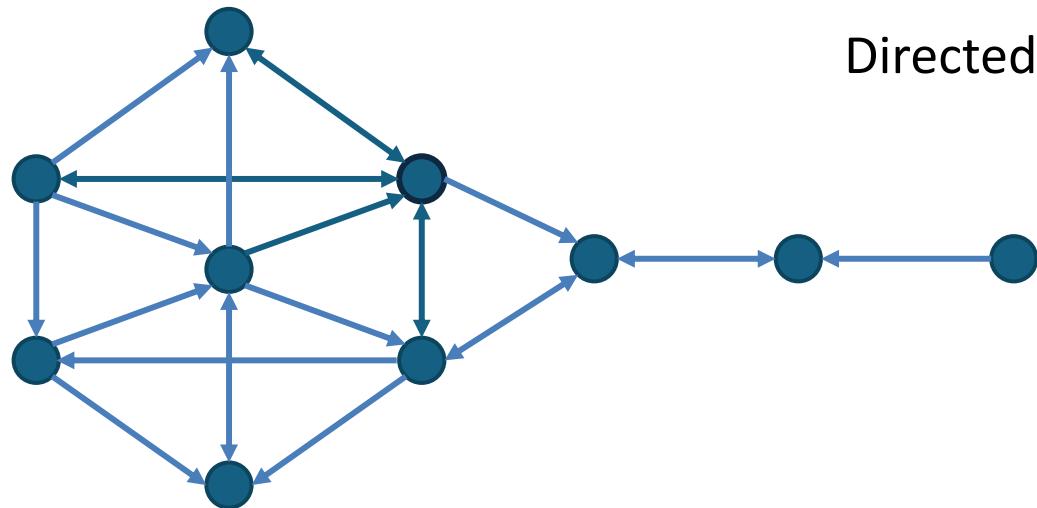
# Network Elements

- Edges, arcs, links and relationships



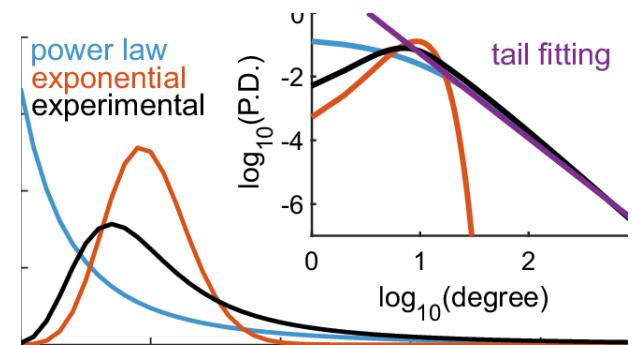
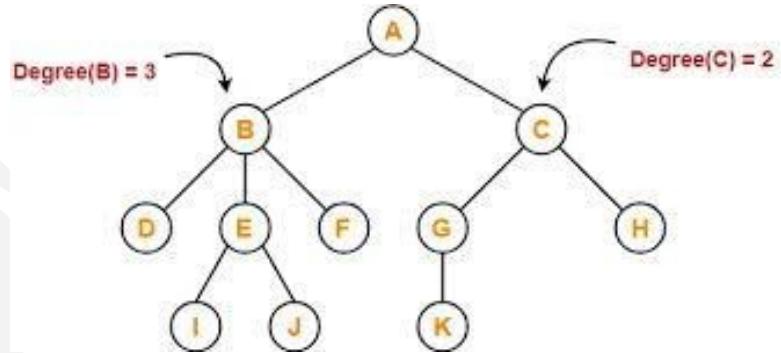
# Network Elements

- Edges, arcs, links and relationships

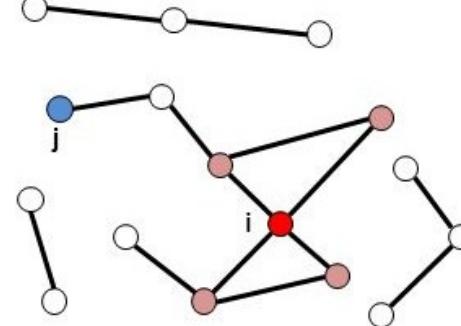


# Node Degree

- number of connections it has to other nodes
- degree distribution is the probability distribution of these degrees over the whole network.



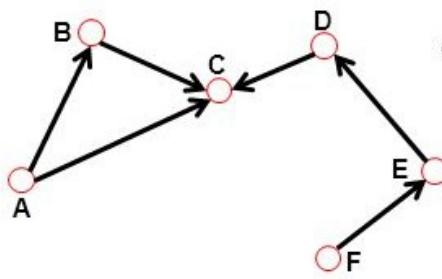
## Undirected



$$\langle k \rangle \equiv \frac{1}{N} \sum_{i=1}^N k_i \quad \langle k \rangle \square \frac{2L}{N}$$

$N$  – the number of nodes in the graph

## Directed

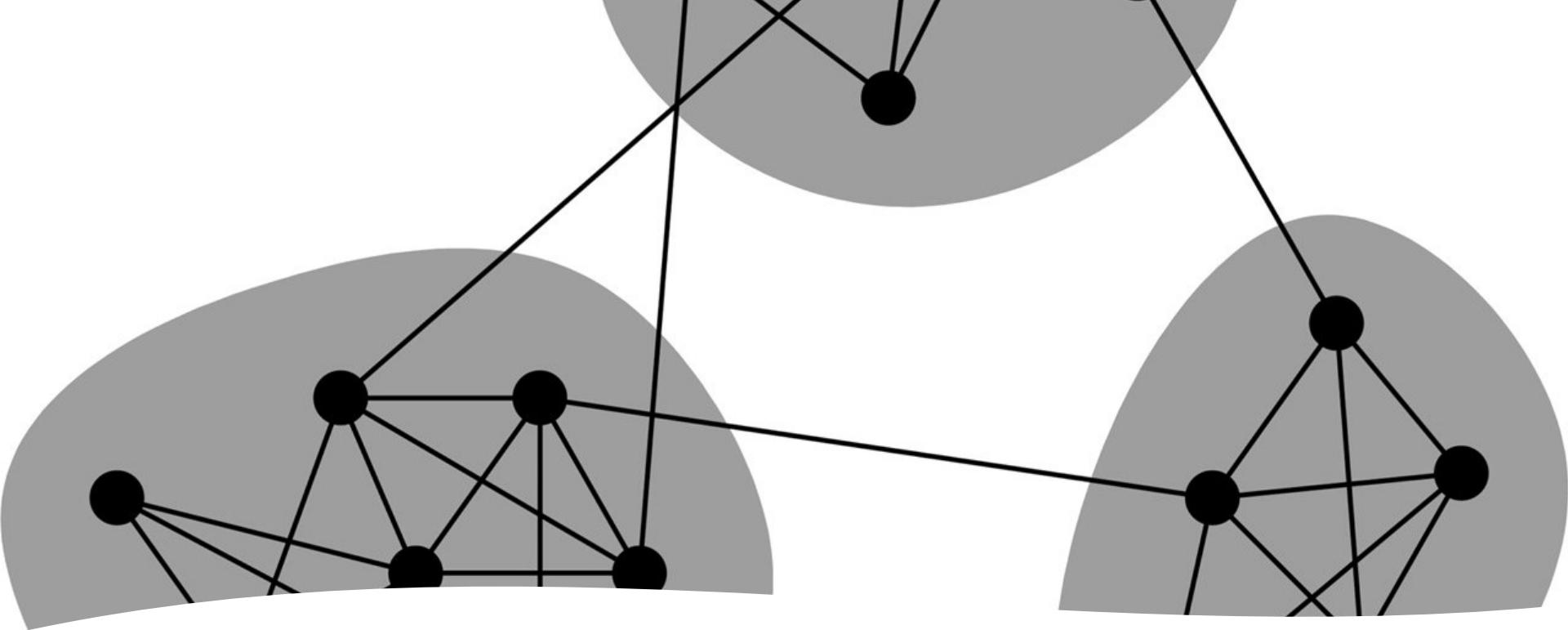


$$\langle k^{in} \rangle \equiv \frac{I}{N} \sum_{i=1}^N k_i^{in}, \quad \langle k^{out} \rangle \equiv \frac{I}{N} \sum_{i=1}^N k_i^{out}, \quad \langle k^{in} \rangle = \langle k^{out} \rangle$$

$$\langle k \rangle \square \frac{L}{N}$$

# Network metrics

- Average Degree (average links per node)



# Network metrics

## Modularity

- is one measure of the structure of networks or graphs.
- It was designed to measure the strength of division of a network into modules (also called groups, clusters or communities).
- Networks with high modularity have dense connections between the nodes within modules but sparse connections between nodes in different modules



assortative



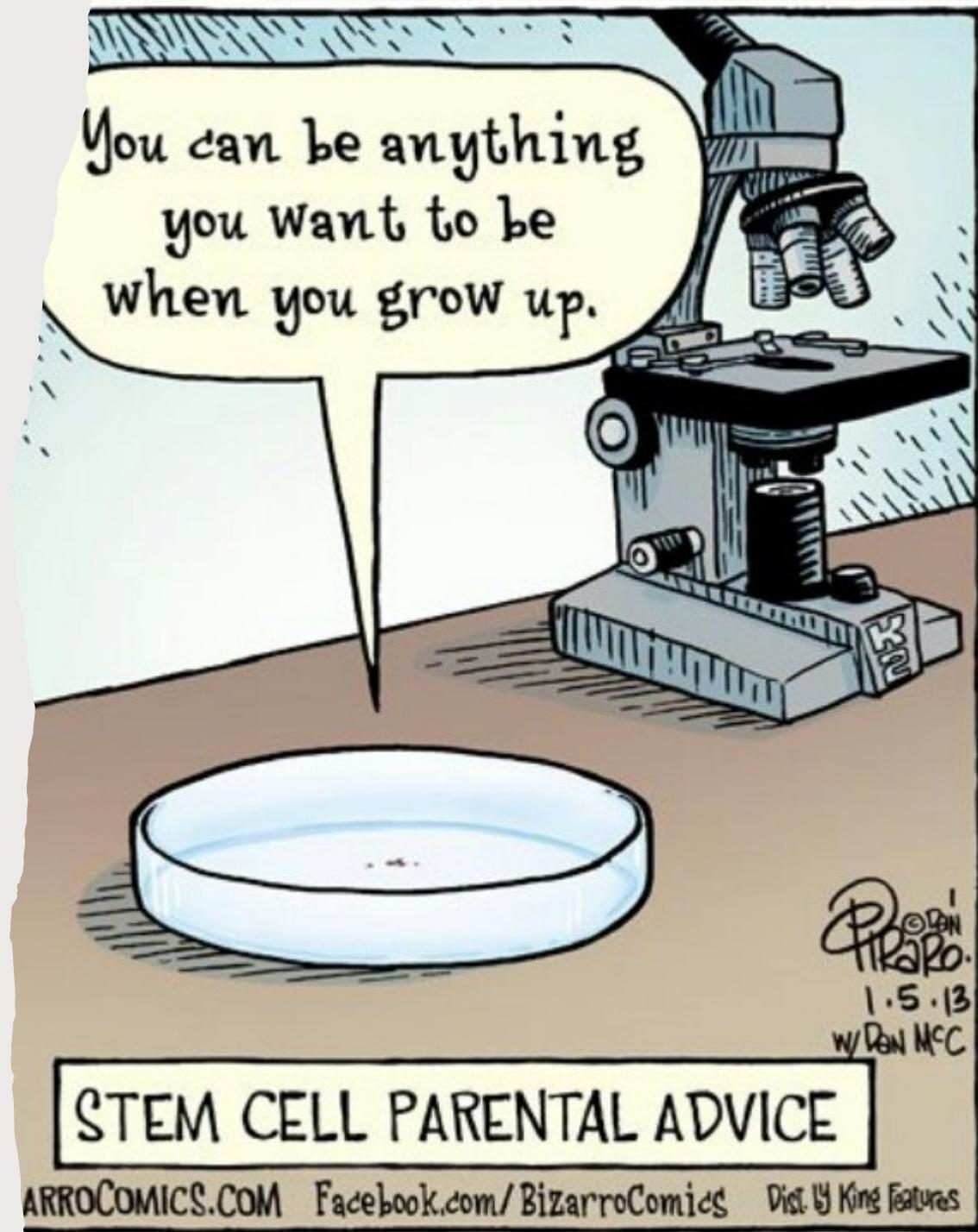
disassortative

## Network metrics

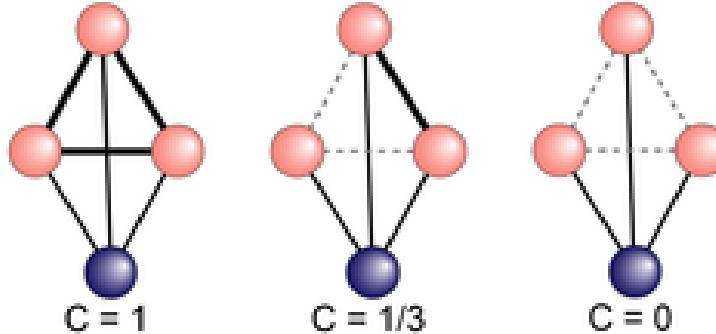
- Connected Components
- Social networks are highly assortative (homophily): high degree nodes connect to other high degree nodes
- technological are disassortative: high degree nodes connect to low degree nodes
- Assortative and disassortative mating

# Node metrics

- Clustering Coefficient
- Centrality
- Closeness Centrality
- Betweenness Centrality
- Eigenvector Centrality



- Triangle Connection
- Actual Connection
- ... Possible Connection

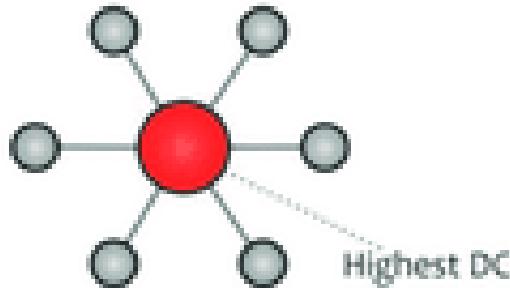


# Node metrics

a clustering coefficient is a measure of the degree to which nodes in a graph tend to cluster together

# Node metrics

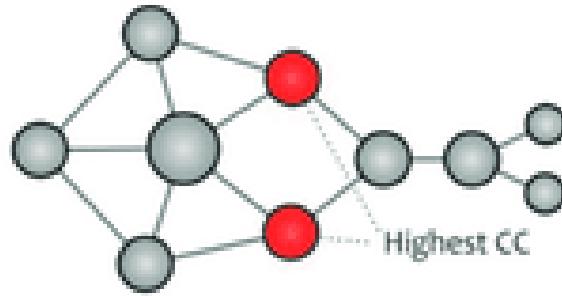
## Degree centrality



Centrality refers to indicators which identify the most important vertices within a graph

# Node metrics

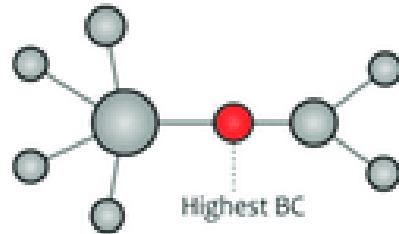
## Closeness centrality



- In connected graphs there is a natural distance metric between all pairs of nodes, defined by the length of their shortest paths.
- The farness of a node is defined as the sum of its distances to all other nodes, and its closeness is defined as the reciprocal of the farness.
- Thus, the more central a node is the lower its total distance to all other nodes.

# Node metrics

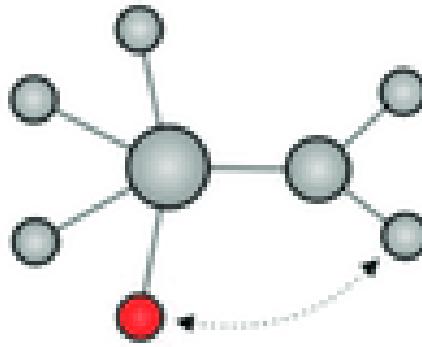
## Betweenness centrality



- Betweenness centrality
- quantifies the number of times a node acts as a bridge along the shortest path between two other nodes.

# Node metrics

## Eigenvector centrality

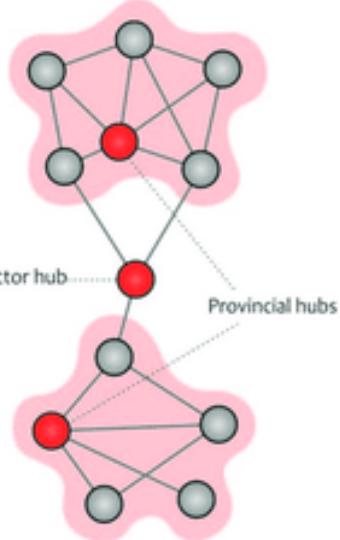


- Eigenvector centrality
- a node is connected to many nodes who themselves have high scores.

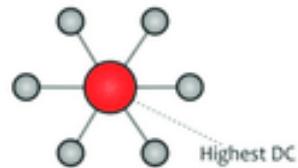
# Node metrics

## Centrality

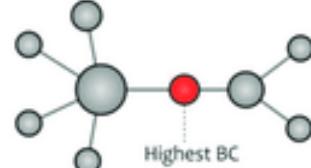
Centrality and hubs



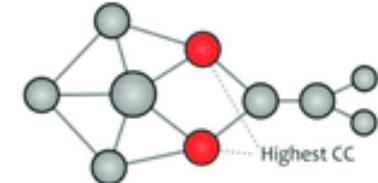
Degree centrality



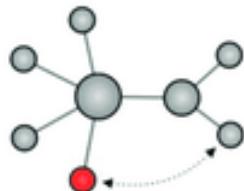
Betweenness centrality



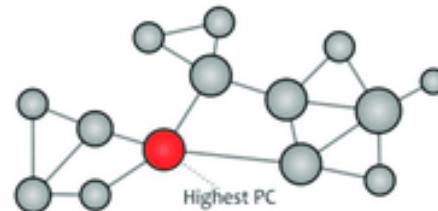
Closeness centrality



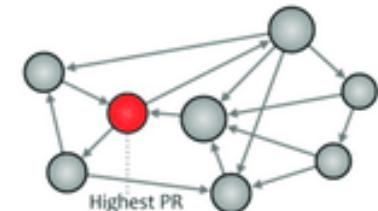
Eigenvector centrality



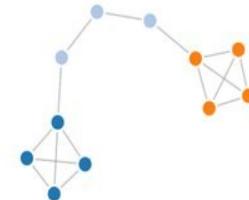
Participation coefficient



PageRank



# Tools

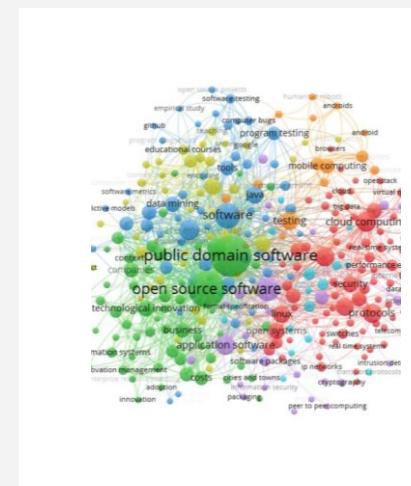
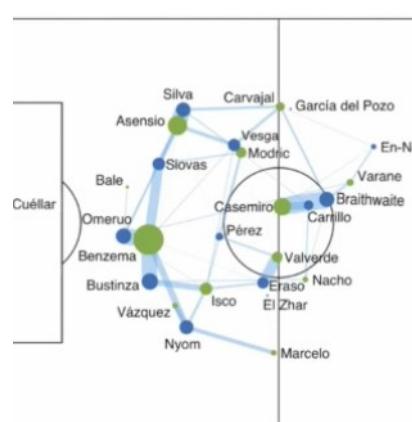
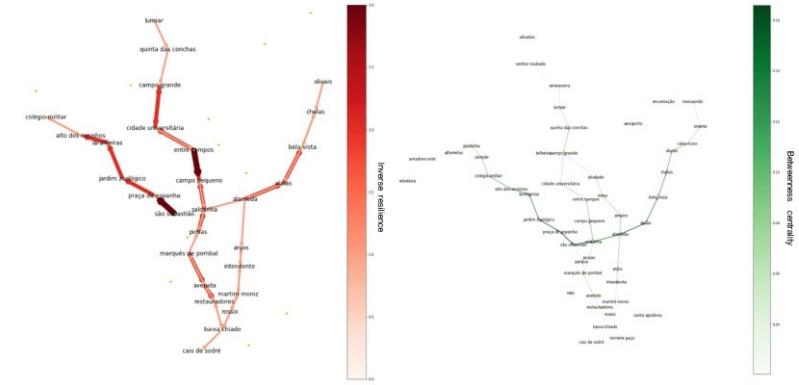


**NetworkX**  
python



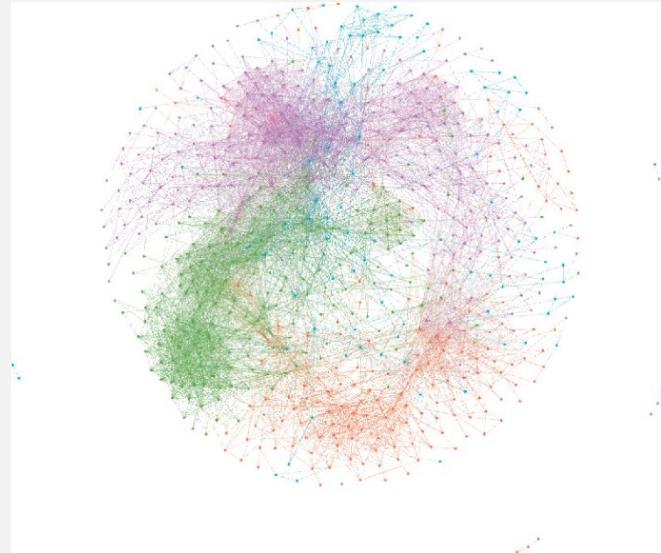
# Applications

- Crime study
- Gang and organized crime
- Research collaboration
- Papers citations
- Social media study
- Team sports



# Applications

- Health and disease spread
- Capital participation
- Equity investment
- Internal communication
- Commercial relationship between enterprises



# Challenges

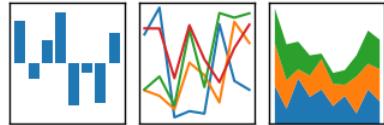
- Internal information
- Secrecy
- GDPR
- Conceptual Complexity
- Main value is obtained by integrate with other approaches
- ...



# Python

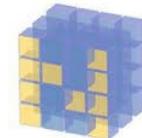
pandas

$$y_{it} = \beta' x_{it} + \mu_i + \epsilon_{it}$$



NetworkX  
python

matplotlib



NumPy

# Conclusions

- Complex Network
- Network Elements
- Measurements
- Node Degree
- Networks Overview
- Node Overview
- Tools
- Applications
- Challenges



# References

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